CHAPTER 9

SAFETY ANALYSIS

In this chapter we discuss several topics related to the safety analysis of a nuclear reactor in Canada.

9.1 LICENSING IN CANADA

The Atomic Energy Control Act, enacted in 1946, provides the legal framework concerning all development and control of atomic energy in Canada. This Act provides specifically for the creation of the Atomic Energy Control Board which is empowered to establish regulations and exercise authority over "prescribed" materials. Prescribed materials includes, not unexpectedly, uranium, thorium, and radioactive isotopes. In addition, it includes special materials required for the exploitation of nuclear energy; this latter provision includes heavy water.

The Atomic Energy Control Board (AECB) has its head office in Ottawa and employs a full-time staff of some 50 professionals. Within the context of nuclear energy development, the Board exercises strict regulatory control through a three stage licensing process:

1. Site Approval;
2. Construction Permit;
3. Operating Licence.

For each of the above three stages, the owner of the nuclear reactor or his agent, must supply the Board with an extensively documented application. For the case of site approval, the document must analyze thoroughly environmental factors (population, geography, geology, meteorology, etc.), it must provide some details on the proposed plant with emphasis on system safety features, and show that general impact criteria, as interpreted by the Board, are met. Public hearings are generally required before the site is approved by the Board. Similar documentation covering appropriate subjects is required for the other two stages before a nuclear reactor is allowed to operate. During operation of the nuclear reactor, the Board receives a continuous flow of documents describing all phases of reactor operation with special emphasis on unscheduled events, radiation effluents and radiation exposures.

9.2 RADIATION EXPOSURE

In Chapter 2, we discussed the phenomena of radioactivity and the several radiations associated with radioactive decay. We indicated that radioactive materials exist in the earth and in our bodies; thus, radiation forms part of our environment.

A discussion of radiation and radiation exposure requires the adoption of appropriate units. One unit, the Curie, has already been discussed in Chapter 2:

1. Curies (Ci) = disintegration rate of an ensemble of radioactive nuclei.
   One Curie equals 3.7×10^4 disintegrations per second.
2. Roentgen (R) = radiation which produces a specified ionizing effect in air.
   One roentgen equals 7.1×10^4 MeV units of energy absorbed in air.
3. Radiation Absorbed Dose (rad) = radiation which causes the deposition of a specified amount of energy in a given medium.
   One rad equals 100 ergs absorbed in a gram of material.
4. Radiation Equivalent Mass (rem) = radiation dose absorbed in a material which includes the relative biological effect of the given radiation and the material.
   One rem equals the rad times a factor known as the quality factor (QF).

Of the above four units, the Curie (Ci) and the Radiation Equivalent Mass (rem) are the most frequently used parameters within the context of radiation protection:

1. the Curie is used to describe the intensity of radioactive decay in a material, while
2. the rem is used to describe limits of radiation exposure of humans.

To place the latter unit into perspective we list here several typical values of radiation dose absorbed, Table 9.1.

Natural background (Cosmic radiation, earth, food, body, etc.)	∿0.130 rem/year
Chest X-ray (each)	∿0.100 rem/year
Dental X-ray (each)	∿0.020 rem/year
Luminous dial wrist watch	∿0.002 rem/year

TABLE 9.1: Radiation dose from some sources.

Atomic energy workers are restricted to an annual dose of 0.5 rem in any one 12 month period while members of the public are restricted to 1/10 this value. All atomic workers and others who use radioactive materials or x-ray machines are required to wear radiation badges; these badges are regularly sent to the Atomic Energy Control Board for examination and to record the radiation dose absorbed by the individual. Similar badges as well as direct and continuous recording radiation monitors are located throughout a nuclear reactor building and along the periphery of a reactor or radiation plant. Stringent control and checking procedures have been established to insure that accurate and reliable data on radiation fields are maintained.

9.3 REACTOR SAFETY

A discussion of reactor safety invariably involves those features which are characteristic of given systems and those systems built-in to provide a response for a specified event. We will touch upon each of these aspects.

As has become clear in the preceding section, the containment of radioactive substances - particularly those occurring as a result of nuclear fission - is of paramount importance. The most significant of these radioactive fission products are krypton, xenon, iodine, cesium and strantium.

For a CANDU reactor it is possible to identify five specific barriers to the movement of these fission products.

1. Diffusion:
   The fission products are formed in the uranium fuel. Resistance to diffusion represents one barrier which tends to contain radioactive isotopes.

2. Sheathing:
   The zirconium alloy which contains the fuel has been designed for the full range of stresses resulting from fuel expansion, fission gas pressures, hydraulic pressures and mechanical handling. This represents the second barrier.

3. Heat Transport:
   The coolant which moves past the zirconium tube to remove the heat energy flow in a closed loop system.

4. Containment:
   The entire heat transport system is housed in a concrete containment system and thus forms a fourth barrier.

5. Exclusion Zone:
   A zone of 3000 feet radius excludes all conventional public activity.

Collectively, these five barriers can be considered to be equivalent to a radiation intensity reduction by a factor of some 100 Million.

The designed safety systems in a reactor must, firstly, be designed high demonstrated level of reliability and, secondly, be independent of other process systems. Reliability of an entire system made up of numerous individual components must total a demonstrated reliability in excess of 0.997. By independence of safety systems it is required that they not be affected by systems such as the turbine plant, the electric power supply, the heat transport system, the control system, etc.

We consider some specific safety systems:

1. Shutdown;
2. Emergency Core Cooling;
3. Containment.

The shutdown system is designed to place or inject a highly neutron absorbing material into the core. This has the effect of removing neutrons and of terminating power production. This shutdown system may consist of gravity-drop spring-assist neutron absorber rods and a liquid injection system which injects a liquid containing a high density of neutron absorbing isotopes into the core.

The **emergency core cooling system** is designed to provide cooling of the core in the event of a major hydraulic description such as a pipe rupture which will prevent the normal removal of heat in a channel. This system consists of a head tank which injects a coolant under pressure into the affected channels. This process is further aided by the feature that the core is the lowest point of the thermal-hydraulic system.

The containment safety system possesses two specific features. In the event of a building pressure or by some other safety trigger, the isolation dampers in the building penetration ducts close immediately. Further, a water dousing system has been installed to condense the steam which might be created in the event of a pipe rupture.